

Emission characteristics of intermediate mass fragments on the residual part of the projectile nucleus

B Debnath, R Talukdar and B Bhattacharjee*

Department of Physics Gauhati University
Guwahati 781 014 Assam India

E mail bb_22@rediffmail.com

Abstract In the study of projectile multifragmentation a number of properties such as multiplicities energy of fragments etc of the emitted intermediate mass fragments (IMFs) are found to vary significantly with Z_b where Z_b is a measure of the mass of the fragmenting system In this work we report the variation of $\langle N_{IMF} \rangle$ with Z_b for 950 MeV/A ^{84}Kr interactions with different targets of photonuclear emulsion The maximum value of $\langle N_{IMF} \rangle$ has been found to vary systematically with the target mass Further from this study it has been observed that Z_b is linearly correlated with the number of emitted projectile protons (N_p) for the studied interactions

Keywords Nucleus nucleus collision multifragmentation intermediate mass fragments

PACS Nos 25.75.-q 25.70.Pq, 13.85.Hd

1. Introduction

In projectile multifragmentation process, a projectile spectator, on excitation, splits into several pieces of intermediate mass fragments (IMFs) which span the mass-range between alpha particle and fission fragments It is believed that studies on the decay of such excited nuclear systems may provide information about the nuclear collision dynamics The sum of all projectile fragments (PFs) with charge $Z = 2$, which is also known as bound charge Z_b , gives the measure of the mass of the fragmenting system [1] Correlation between average number of IMFs and the mass of the fragmenting system is one of the most interesting aspects of studying projectile multifragmentation For a given collision system, the magnitude of Z_b is independent of the beam energy and is also taken as a measure of the degree of centrality of the collision [2,3] On the other hand, when the variation of $\langle N_{IMF} \rangle$ is studied with Z_b for a given projectile, in reactions with the lighter targets, the maximum value of the mean multiplicities of IMFs depend on the bombarding

energy if the later is less than a specific minimum value. As reported by ALADIN group [4], specific minimum bombarding energies are about 400, 800 and 1000 MeV per nucleon for collisions of gold projectiles with aluminium, carbon and beryllium targets respectively. From their report it is therefore readily evident that for the same projectile, as the target mass increases, the specific minimum value of the beam energy for attaining the maximum mean multiplicity of IMFs, when plotted against Z_p , decreases.

An advantage of studying high energy nucleus-nucleus collisions with nuclear emulsion is that the technique provides an opportunity to study nuclear reactions with variable targets (such as H, C/N/O and Ag/Br). As in most of the emulsion works, the bombarding energy is generally a few GeV/A or above, no such work has so far been reported for which the incident beam energy is found to be below the critical minimum for the studied interactions. As a result, no variation in the maximum value of $\langle N_{IMF} \rangle$ could be seen with the variation of target mass for the studied emulsion reactions.

As the incident beam energy for the emulsion pellicles of the present investigation is, significantly low which is 950 MeV/A, in this work an attempt has therefore been made to study the variation of $\langle N_{IMF} \rangle$ with Z_b for ^{84}Kr interactions with various targets of photonuclear emulsion to conclude whether the beam energy of the present investigation is above or below the specific minimum value for the studied interactions.

Further, a number of workers have taken the number of projectile protons (N_p) as a good measure of the impact parameter of a collision [5,6]. The correlation between $\langle N_{IMF} \rangle$ and N_p is another important aspect of projectile multifragmentation that has been studied in details by different workers [6]. As both Z_b and N_p are taken as a measure of degree of centrality of the collision, an attempt has also been made to find the correlation between these two parameters for interactions of same Kr projectile with various targets of nuclear emulsion.

2. Experimentals

The technique of nuclear emulsion allows for a complete detection of all PFs with charge $Z \geq 1$ and is the most suitable method to study all the possible projectile fragmentation channel. The capability of emulsion to record all the PFs irrespective of their charge and emission angle makes emulsion experiments superior or at least competitive to other experimental technique for the study of projectile multifragmentation [2,7]. For the present investigation, NIKFI BR-2 nuclear emulsion pellicles irradiated horizontally with ^{84}Kr beam having energy 950 MeV/A at SIS synchrotron at GSI, Darmstadt were used. These emulsion plates were line scanned and various tracks were then classified according to the standard emulsion terminology on the basis of their ionization (I) in the emulsion [8]. The identification of PFs is unique due to their confinement in the extreme forward angle, $\theta_{PF} = 0.2/p_L$ radian, where p_L is the beam momentum. The charge of different PFs were measured by estimating various track parameters such as blob density (B), gap density (H), the Gap Length Coefficient (G), δ -rays density and track width [9]. For this study, only those non-interacting singly charged projectile fragments (protons, deuterons and tritons) are

considered as N_p which are emitted within 0-7 degree opening angle and are free from comparatively large scattering. Charge of $Z = 1$ PFs are estimated by blob and gap counting method.

3. Results and discussion

Frequency distribution of multiply charged projectile fragments with $Z \geq 2$ emitted from $^{84}\text{Kr-H}$, $^{84}\text{Kr-C/N/O}$, $^{84}\text{Kr-Em}$ and $^{84}\text{Kr-Ag/Br}$ interactions are plotted in Figure 1. From this figure it can be readily seen that, irrespective of target mass, the emission of light projectile fragments are most abundant. In case of heavier target, the remnant part of the projectile nucleus splits into lighter fragments more preferably. On the other hand, heavy PFs are emitted more frequently from the lower target mass system. These results are in good agreement with the results reported by Cherry *et al.* [10].

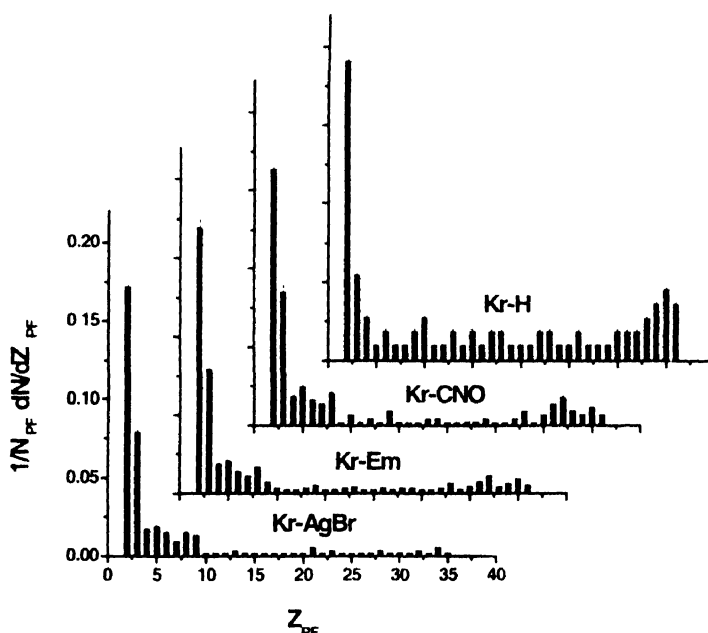


Figure 1. Frequency distribution of multiply charged projectile fragments with $Z \geq 2$ for the collisions of krypton beam with different targets of nuclear emulsion at 950 MeV/A. The distributions for various targets are plotted on the same scale.

It has been reported by ALADIN group [3] that in case of collisions with lighter targets, incident beam energy should be greater than a specific minimum value in order to achieve a complete disassembly of the projectile spectator thereby attaining the maximum fragment multiplicity. Keeping this result in our mind, we have investigated the variation of $\langle N_{IMF} \rangle$ with Z_p for collisions of 950 MeV/A ^{84}Kr with different targets of nuclear emulsion and the results are plotted in Figure 2(a)-(c).

From these plots one can easily observe the increase of maximum value of mean multiplicity of IMFs ($\langle N_{IMF} \rangle_{\max}$) with the increasing target mass for the present beam energy of $E/A = 950$ MeV for ^{84}Kr . Such variation of $\langle N_{IMF} \rangle_{\max}$ with the variation of target

mass suggests that the available beam energy of present investigation is less than the critical minimum value of bombarding energy for the interactions of ^{84}Kr with lighter mass targets of nuclear emulsion. It may be noted that, due to low statistics, we have not reported here the plot for $\langle N_{\text{IMF}} \rangle$ vs Z_b for ^{84}Kr -H interactions. Nevertheless, when it was

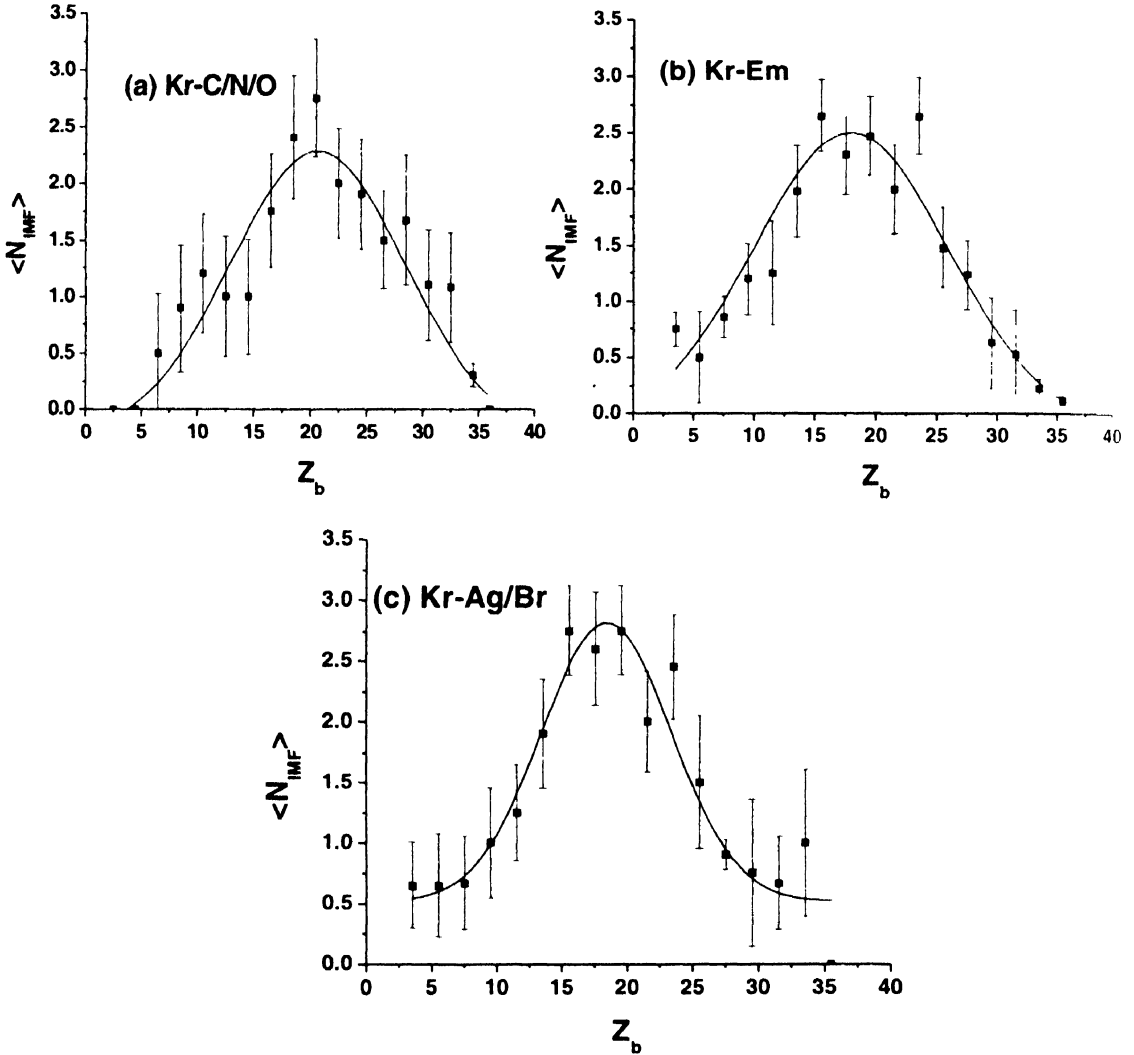


Figure 2. Average multiplicity distribution of IMFs as a function of Z_b for the interactions of (a) ^{84}Kr -C/N/O (b) ^{84}Kr -Em and (c) ^{84}Kr -Ag/Br.

tried to fit the experimental data points obtained from ^{84}Kr -H interactions, the value of $\langle N_{\text{IMF}} \rangle_{\text{max}}$ was found, as expected, to be less than the all other values of $\langle N_{\text{IMF}} \rangle_{\text{max}}$. The mean and maximum values of $\langle N_{\text{IMF}} \rangle$ for various interactions of present investigation are listed in Table 1. Jain *et al* [11] have reported the average and maximum values of $\langle N_{\text{IMF}} \rangle$ for ^{197}Au -Em interactions at 10.6 A GeV to be 2.68 ± 0.10 and 3.65 ± 0.82 respectively.

Table 1. Values of average $\langle N_{IMF} \rangle$, maximum mean multiplicities of IMFs and R^2 of the best fit of simple Gaussian distribution of the experimental data

Target	Avg. $\langle N_{IMF} \rangle$	Max $\langle N_{IMF} \rangle$	$R^2(\%)$
Ag/Br	1.55 ± 0.10	2.82 ± 0.23	93.1
Em	1.36 ± 0.10	2.51 ± 0.12	94.8
C/N/O	1.2 ± 0.14	2.27 ± 0.18	93.1
H	0.72 ± 0.13	1.09 ± 0.31	—

As mentioned in section 1, both the number of projectile protons (N_p) and the mass of the fragmenting system (Z_b) are related with the geometry of the collision. To find the correlation between these two parameters, the variation of $\langle Z_b \rangle$ with N_p for the interactions of ^{84}Kr with different emulsion targets are studied and the results are plotted in Figure 3.

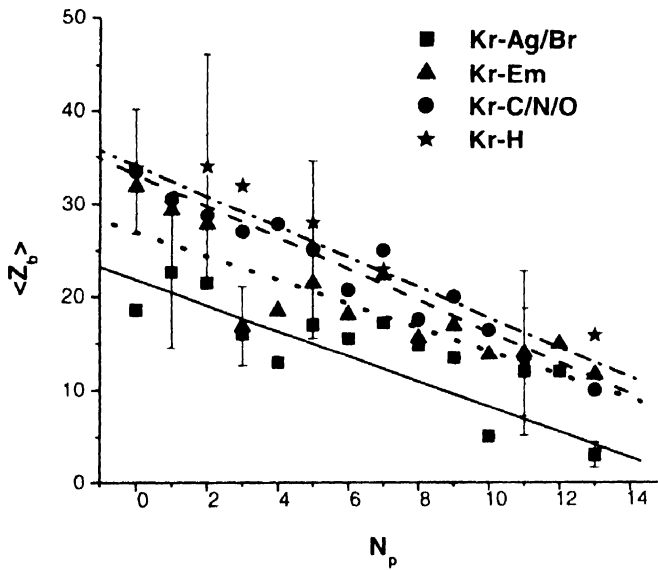


Figure 3. Correlation between average Z_b and N_p for the reactions of ^{84}Kr with Ag/Br, Em, C/N/O and H at 950 MeV/A. Solid (Ag/Br), dot (Em), dash (C/N/O) and dash dot (H) lines are the best fitted lines for the respective experimental data points

As expected, a negative correlation of $\langle Z_b \rangle$ with N_p is readily evident from this plot. The errors shown in this figure are the maximum and minimum errors for various data points and are estimated as independent statistical errors only. Though the errors for the above plots are relatively large due to poor statistics of studied interaction of each type, nevertheless one can not ignore a systematic increase in the values of $\langle Z_b \rangle$ for a particular value of N_p with the decrease of target mass. However, no such regular pattern could be observed from this plot on the probable dependence of the strength of the correlation with the target mass. The values of the slopes for the best fitted lines of the data points for the reactions with H, C/N/O, Em and Ag/Br are respectively found to be -1.62 ± 0.20 , -1.68 ± 0.14 , -1.27 ± 0.25 and -1.36 ± 0.27 .

4. Summary

From the result obtained from this investigation it has been observed that the mechanism of fragmentation of spectator part of the projectile nucleus depends on the target mass. Emission of heavy PFs is more frequent in lighter target mass system. For the interactions studied under the present investigation with the available beam energy, the complete disassembly of the projectile spectator with the light targets have not been achieved resulting an increase in the values of $\langle N_{IMF} \rangle_{\max}$ with the increase of target mass. As the mass of the target decreases for the studied krypton interactions, $\langle Z_b \rangle$ values are found to increase for a specific value of N_p .

Acknowledgment

Authors thankfully acknowledge the financial assistance of Department of Atomic Energy, Board of Research in Nuclear Sciences, Mumbai to carry out this piece of research work in the form of a research project.

References

- [1] J Hubele *et al*, *Z Phys* **A340** 263 (1991)
- [2] A Dabrowska *et al* *Acta Physica Polonica* **B31(3)** 725 (2000)
- [3] M L Cherry *et al*, *Phys Rev* **C52(5)** 2652 (1995)
- [4] A Schuttauf *et al*, *Nucl Phys* **A607** 457 (1996)
- [5] C Cavata *et al*, *Phys Rev* **C42** 1760 (1990)
- [6] P L Jain and G Singh *Phys. Rev* **C46(1)** R10 (1992), *Phys Rev* **C47(5)** 2382 (1993)
- [7] B Bhattacharjee *Nucl Phys* **A748** 641 (2005), B Bhattacharjee and S Sengupta *Int J Mod Phys* **E14(8)** 1223 (2005)
- [8] B Bhattacharjee *et al*, *Radiant Meas* **36** 291 (2003)
- [9] P H Fowler and D H Perkins *Phil. Mag* **46** 587 (1955), C F Powell *et al*, *The Study of Elementary Particles by Photographic Method* (London Pergamonn) p 093 (1959) W H Barkas *Nuclear Research Emulsion* (New York, London . Academic Press) **Vol 1** (1963)
- [10] M L Cherry *et al*, *Eur Phys. J* **C5** 641 (1998)
- [11] P L Jain *et al*, *Phys Rev* **C50(2)** 1085 (1994)